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Rhode Island Emissions and Safety Program
2011 On-Road Vehicle Survey

Prepared for:

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January 2012

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I. Summary

In 2011, Envirotest conducted a 0.5% on-road vehicle emissions survey for SysTech International, LLC as part of the Rhode Island Vehicle Emissions and Safety Testing Program.

On-road survey data was collected on 9 days from September 12 through September 21, 2011 by an RSD-4600 on-road remote sensing device van that measured exhaust emissions of vehicles as they drove by. Emissions were successfully measured and plates were visible on 41,777 vehicles. Over 84% of the plates displayed were Rhode Island plates.

The RSD-4600 system measures hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen (NO) and smoke. Average emissions of the on-road light-duty vehicles matched to Rhode Island registrations were 15 ppm HC, 0.10 % CO and 138 ppm NO.

The results presented in Figure I-1, I-2 show that older vehicles have higher emissions for HC and NO pollutants that contribute to the formation of ozone. On average, 1995 & older models were between six and twelve times dirtier than the 2001 and newer models.

Figure I-3 shows the approximate overall contribution by model year. Vehicle models 1995 & older contributed only 5% of Vehicle Miles Traveled (VMT) but still accounted for almost one quarter of on on-road HC, CO and NO emissions. Vehicle models 1996-2000 contributed 20% of VMT and 30-45% of emissions. Vehicle models 2001-2011 contributed 75% of VMT and 30-45% of emissions.

Figure I-1 HC Emissions by Age

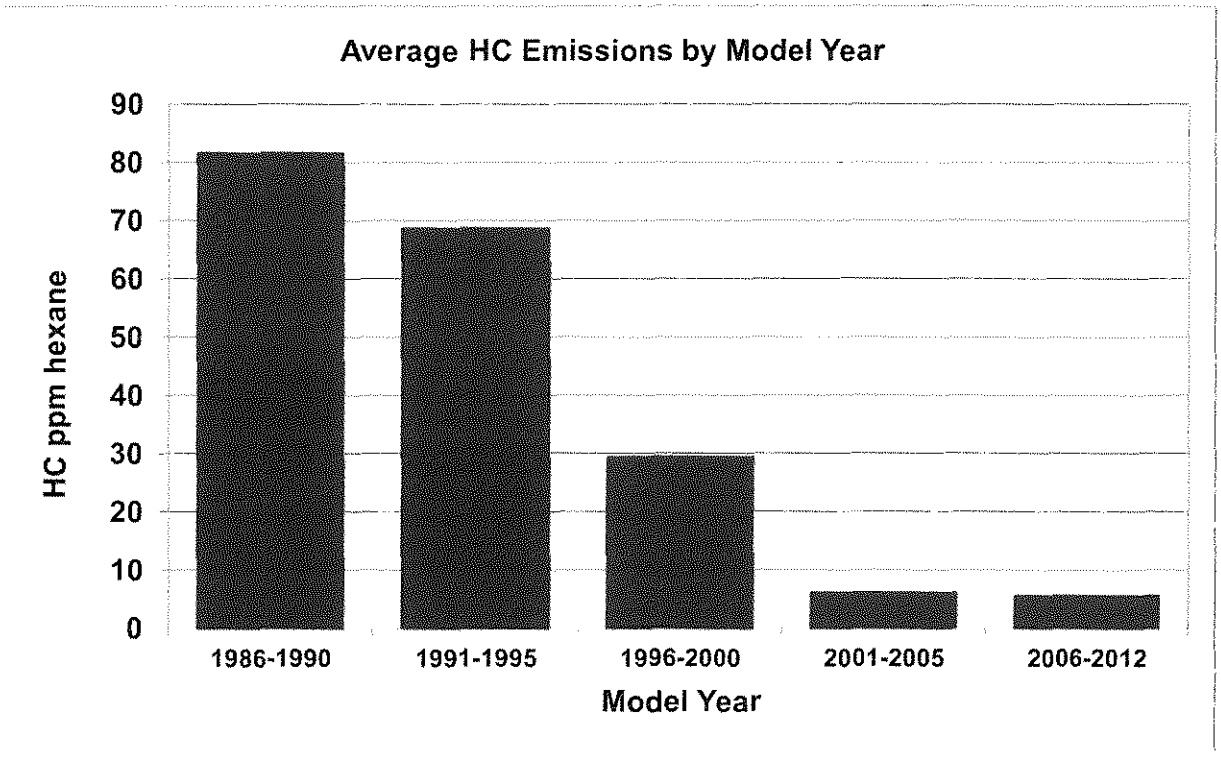


Figure I-2 NO Emissions by Age

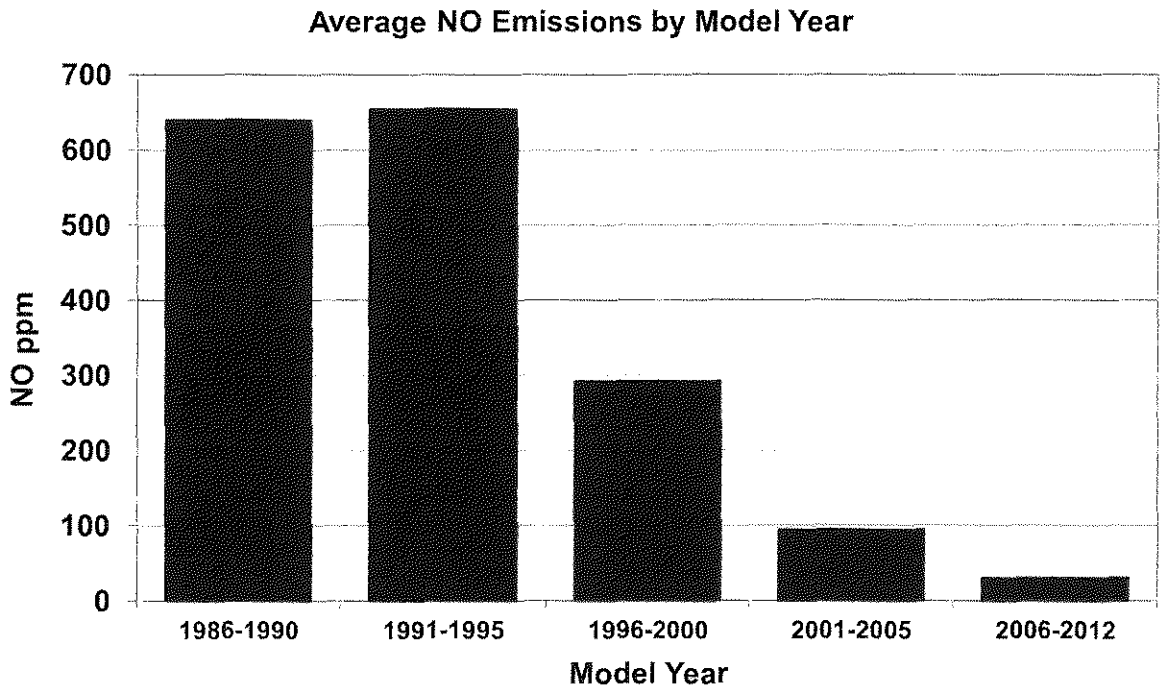
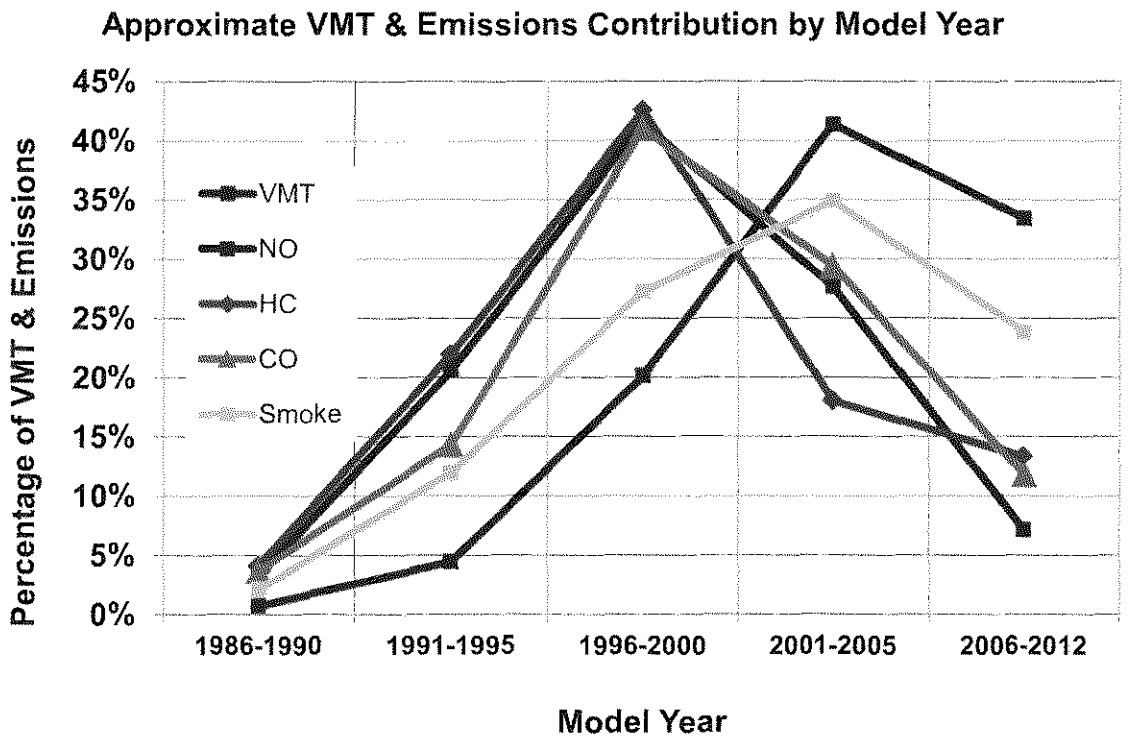


Figure I-3 Approximate VMT & Emissions Contributions by Age



II. Description of the RSD Project

A. General

1. *Project Requirements*

The Rhode Island Department of Environmental Management (DEM) manages an enhanced vehicle emissions and safety program subject to the Clean Air Act Amendments of 1990 that includes an on-road/remote sensing element. The Clean Air Act Amendments require that a minimum of 0.5% of the eligible motor vehicle population in the I/M area be tested annually.

Section 51.371 of the Code of Federal Regulation (CFR) covering Enhanced I/M programs defines on-road testing as the measurement of HC, CO, NO and/or CO2 emissions on any road or roadside in the non-attainment area or the I/M program area. On road testing is required in enhanced I/M areas and is an option for basic I/M areas.

The general requirements specified in CFR 51.371 are:

> (1) On-road testing is to be part of the emission testing system, but is to be a complement to testing otherwise required.
>
> (2) On-road testing is not required in every season or on every vehicle but shall evaluate the emission performance of 0.5% of the subject fleet, including any vehicles that may be subject to the follow-up inspection provisions of paragraph 4 (below), each inspection cycle.
>
> (3) The on-road testing program shall provide information about the emission performance of in-use vehicles by measuring on-road emissions through the use of remote sensing devices or roadside pullovers including tailpipe emission testing. The program shall collect, analyze and report on-road sensing data.
>
> (4) Owners of vehicles that have previously been through the normal periodic inspection and passed final retest and found to be high emitters shall be notified that the vehicles are required to pass an out-of-cycle follow-up inspection; notification may be by mailing in the case of remote sensing on-road testing or through immediate notification if roadside pullovers are used.

2. *Contractor*

The Remote Sensing division of Environmental Systems Products Holdings Inc., subsequently known as Envirotest Systems Holdings Corp. (Envirotest) was sub-contracted to conduct the on-road survey by the Emissions and Safety

contractor SysTech International, LLC. Headquartered in Tucson, Arizona, the Remote Sensing division of Envirotest has more experience with remote sensing than any other company. Envirotest uses technology derived from that originally developed at Denver University with whom Envirotest has a royalty agreement.

3. Description of RSD

Theory of operation

The remote sensing device is a system designed for a non-intrusive measurement of vehicle emissions. It generates and monitors a non-dispersive infrared and ultra-violet beam emitted and reflected approximately 10 to 18 inches above ground preferably across a single lane road. Gasoline, diesel, or other fossil fuel powered vehicles drive through this beam and the exhaust interferes with this transmission of the beam. Quantifying the interference enables the calculation of tailpipe concentrations of CO, HC, CO2, and NO. A camera simultaneously captures a digitized video image of the rear of the vehicle and its license plate.

Equipment

The particular unit deployed in Rhode Island is an RSD-4600 system. This is a third generation remote sensing system based on a technical platform developed at the University of Denver by Dr. Donald Stedman. The trademark name for the remote sensing system is AccuScan™.

Each mobile unit includes the equipment required to provide measurement of emissions as well as speed and acceleration readings and license plate recognition. Five main components comprise the AccuScan™ system:

- Infrared source detector module (SDM);
- Video system;
- Control console with computer system;
- Laser based speed and acceleration measurement system;
- Automated license plate reading system.

The primary combustion gases HC, CO, CO2 and NO are measured simultaneously along the same optic path to ensure the proper application of the combustion gas equations. To avoid interference between vehicles, the AccuScan™ unit is capable of completing the vehicle emission measurement within 0.6 second and of completing all measurements for a vehicle including emissions, speed, acceleration and plate image within one second.

The AccuScan™ unit takes multiple rapid readings for each vehicle to characterize the exhaust plume profile and evaluate whether a valid

measurement of a vehicle's exhaust has been achieved. The criteria include how much vehicle exhaust plume is available for the duration of a 0.6 second sampling period, evaluation of whether plume measurements are consistent with normal plume dissipation, and correction for changes in background concentrations of emissions.

AccuScan™ units are certified to meet accurate measurement of calibration gas trailed by a specially modified vehicle under controlled conditions using a quad-blend of HC, CO, CO2 and NO:

- Carbon monoxide (CO): ±10% or 0.25% {whichever is greater} for all expected concentrations less than or equal to 3.0%, and ±15% for all CO expected concentrations above 3.0% CO.
- Hydrocarbon (HC): ±150 parts-per-million (ppm) or ±15% of the expected HC concentration {whichever is greater} throughout the range of HC concentrations. Hydrocarbon measurements are expressed in their hexane equivalent measurement.
- Oxides of nitrogen (NO_x): ±250 parts-per-million (ppm) or ±15% of the expected NO_x concentration {whichever is greater} throughout the range of NO_x concentrations.

The mobile unit is equipped with a speed and acceleration measurement system that uses extremely accurate low energy lasers to calculate the speed of the vehicle to within +/- 0.5 mile per hour and acceleration to within +/- 0.3 miles per hour per second at the moment exhaust is measured.

The system captures emissions readings and rear pictures of vehicles that pass through the AccuScan™ beam. The video and emissions readings taken are stored directly on a removable media disk and can be used for future reference.

Data collected

For each vehicle the following information is collected:

- Plate number;
- HC, CO, CO2, and NO emission concentrations;
- Max CO2;
- Speed and acceleration.

B. Overview of 0.5% Sample

1. Sample Design Criteria

The objective is to obtain the 0.5% sample from sites that will be generally representative of vehicles operating in the I/M program areas. For this

purpose eight measurement locations were selected in Kent and Providence Counties.

2. Sample Site Characteristics

Site selection is critical to obtaining RSD measurements that are representative of vehicle operation. Recommended site attributes include:

- Absence of cold start vehicle operating conditions;
- Sites where vehicles will generally be accelerating or driving at a steady speed uphill to avoid the highly variable tailpipe emissions that can occur under deceleration;
- Absence of enrichment due to high load conditions;
- Single lane operation;
- High volume traffic;
- Unobtrusive citing of the remote sensing equipment;
- Stability in the traffic mix from one year to the next;
- Adequate median space for safe operation of the RSD equipment.

C. Sites selected for studies

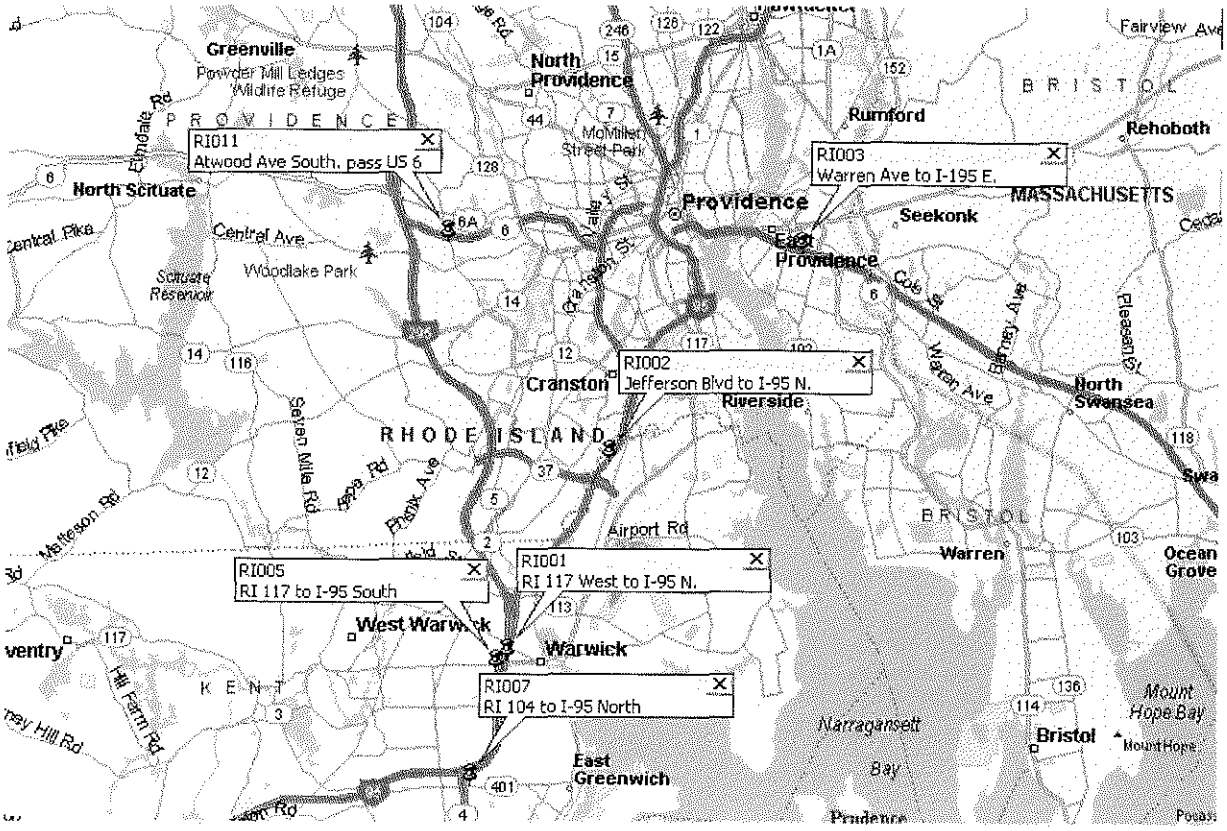
Table II-1 lists the site locations selected for the 0.5% sample and Figure II-1 shows the locations. All the sites selected are on-ramps or exit loops that provide the required physical characteristics of an appropriate RSD site. Sites were pre-qualified for:

- Single lane operation with space for the RSD equipment to be deployed without disrupting traffic flow
- A satisfactory percentage of valid readings;
- An adequate traffic volume.

Table II-1 RSD Sites

Site	Location	County
RI001	from RI 117 West to I-95 North	Kent
RI002	from Jefferson Blvd. West to I-95 North	Kent
RI003	from Warren Ave East to I-195 East	East
RI005	from 117 East/West to I-95 South	Providence
RI007	from RI 401 East/West to I-95 North	Kent
RI011	Atwood Ave South, just past US 6	Providence

Figure II-1: Site Locations



D. Sources of Data and Description of Elements

Data used in the analyses in this report come from two primary sources, the RSD on-road measurements and the Division of Motor Vehicles (DMV) registrations database.

In the following description of data elements, key fields that are used to access other tables are shown in **bold**.

1. RSD Measurements

For each vehicle the following information is collected:

- **Vehicle Plate or tag;**
- Date and Time;
- **Site Reference;**
- HC, CO, CO2, and NO;
- Speed and acceleration.

2. RSD Sites

- **Site Reference;**
- Description of location;
- Slope of site in degrees;

3. Vehicle Registration Data

SysTech matched the RSD observed vehicle plates to vehicles tested in the I/M program and to registration information. Using the vehicle plate identified by RSD, the test and registrations file were accessed to determine the vehicle make, model and model year.

E. Data Limitations

1. RSD Unit Accuracy

As previously noted, the AccuScan™ unit's measurement specifications (On Road Using Dry Gas from 20 to 120°F) are:

- CO - ±0.25 of concentration or ±10% of reading whichever is larger.
- HC - ±150 ppm hexane or ±15% of reading whichever is larger.
- NOx - ±250 ppm or ±15% of reading whichever is larger.

Unit certifications are conducted at Envirotest's facilities in Tucson, AZ, USA. Certification activities include usage of a specially outfitted audit vehicle that carries compressed gas cylinders of known concentrations of gaseous pollutants. The audit vehicle releases these gases at driver selected times just prior to reaching the Remote Sensing Device (RSD), continuing past the RSD, and for a few seconds beyond passage of the RSD. A total of twelve concentrations of gases combined into three blends of compressed gases are used for the certification activities. These concentrations are as follows:

- CO: .2%, .5% 1.00%, 2.75% and 5.00%
- HC: 25 ppm, 250 ppm, 1000 ppm, 1500 ppm, 3000 ppm hexane equivalent (propane is used for the audit gas)
- NO: 250 ppm, 500 ppm, 1500 ppm, 2000 ppm, 3000 ppm

III. Summary of Data Collection

A. RSD Sample Quantity

1. Data Collection Summary

The number of light-duty vehicles registered in Rhode Island is approximately 750,000. The requirement of a 0.5% sample of subject vehicles therefore requires 3,750 measurements per year.

In total, 41,777 RSD measurements with a visible plate were made from September 12 - 21, 2011 and 84% of the vehicles displayed Rhode Island plates.

Table III-1 shows a daily count by site of the measurements collected and how many measurements had valid emission measurements, valid speed and acceleration measurements and readable plates.

Table III-1 Daily Remote Sensing Measurements by Site

Site	Location	Unit	Date	Valid Emissions, Speed and Visible Plate	Valid Emissions, Speed and Visible RI Plate
RI001	from RI 117 West to I-95 North	07064620	13-Sep-11	3,975	3,453
RI002	from Jefferson Blvd. West to I-95 North	07064620	20-Sep-11	3,303	2,561
RI003	from Warren Ave East to I-195 East	07064620	14-Sep-11	4,320	3,146
RI003	from Warren Ave East to I-195 East	07064620	19-Sep-11	3,877	2,800
RI005	from 117 East/West to I-95 South	07064620	15-Sep-11	2,134	1,957
RI005	from 117 East/West to I-95 South	07064620	21-Sep-11	1,441	1,324
RI007	from RI 401 East/West to I-95 North	07064620	12-Sep-11	8,474	7,314
RI007	from RI 401 East/West to I-95 North	07064620	16-Sep-11	8,665	7,499
RI011	Atwood Ave South,just past US 6	07064620	17-Sep-11	5,588	5,167
Total				**41,777**	**35,221**

2. Origin of Vehicles by State

The vast majority of vehicles measured displayed Rhode Island plates. The other States originating a significant fraction of vehicles driving in Rhode Island were Massachusetts (11%), Connecticut (1%) and New York (<1%).

Table III-2 Remote Sensing Measurements by State

State	Plates	%
RI	35,221	84%
CT	518	1%
MA	4,465	11%
NY	201	0%
Other	1,372	3%
Total	41,777	100%

3. *Data Screening to Obtain Representative Fleet Emissions Estimates*

a) Outliers

Outlying values may be caused by unusual on-road conditions, e.g. the passage of a large dirty vehicle that temporarily elevates the background emissions and causes a following vehicle to appear cleaner than the background. There were no HC, CO or NO values found below -250 ppm HC or -0.25 CO or NO <-500ppm. Thus all values were within the equipment tolerance.

b) The Effect of Vehicle Specific Power on Emissions

Under moderate to heavy load conditions, vehicle engines will enter enrichment modes that can increase emissions many times. Under these conditions, vehicles that would run cleanly within the operating range of the FTP will have much higher emissions. If remote sensing measurements are to be used to identify excess emissions, it is desirable to screen out measurements of vehicles legitimately operating in enrichment mode. These readings may bias the average results and the vehicles may be incorrectly classified as high emitters. Therefore, it is useful to have a performance measure for determining whether a vehicle was operating within an acceptable power range when it was measured by RSD.

Engine load is a function of the vehicle speed and acceleration, the slope of the site, vehicle mass, aerodynamic drag, rolling resistance, and transmission losses. The effects of these forces can be aggregated into a single parameter called vehicle specific power (VSP), which was the topic of a presentation at the Ninth CRC On-road Vehicle Emissions Workshop[1]. The CRC E-23 Project[2,3] further developed the concept of vehicle specific power. In the Denver Remote Sensing Clean Screening Pilot[4] the analysis was further extended by stratifying the vehicles by age. In 2002, EPA adopted the use of VSP as a parameter for predicting vehicle emissions in the emissions inventory model MOVES that is expected to replace Mobile6[5].

Jimenez[6] observed that many recent modern cars go into enrichment at power levels soon after the FTP maximum of 22kW/t. At low power and during engine overrun, tailpipe emission pollutant to CO2 ratios become unstable because there is limited

CO2. The EPA draft guidance[7] on the use of RSD for fleet evaluation recommends using remote sensing measurements within the specific power range of 5kW/t to 20kW/t for comparative fleet emission evaluations.

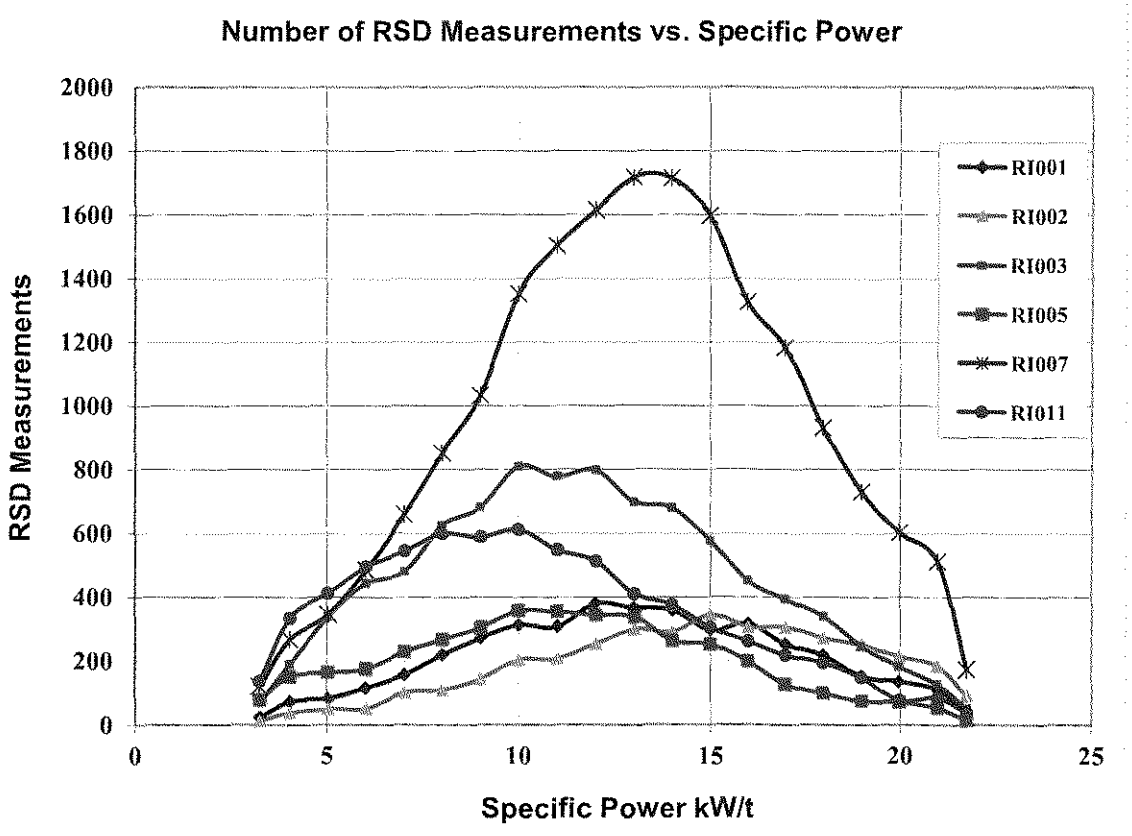
Figure III-1 shows the distribution of measurements vs. specific power at the eight Rhode Island sites. Records with VSP <3 and >22 were already discarded during tag editing. The lower and upper end restrictions of 5 and 20kW/t cut an additional 3,123 records.

c) Screening Out Excessive Cold Starts and Exhaust Steam Plumes

When vehicles are cold, the fuel/air mixture is enriched and the catalytic converter is not functioning effectively. Consequently tailpipe emissions from cold vehicles are elevated and are not typical of normal vehicle operation. Modern vehicles warm-up within a few minutes. Therefore, provided sites are not immediately adjacent to large residential tracts, cold starts are not normally a problem at RSD sites.

Exhaust gases include a substantial amount of water vapor as a result of hydrocarbon fuel combustion. In cold, humid conditions the water vapor in the exhaust condenses as the exhaust plume cools forming water droplets that appear as steam. This can result in elevated RSD readings for HC.

Figure III-1 Number of RSD Measurements by Specific Power by Site



Few vehicles less than five years old have high HC emissions. This fact is used to look for hours when steam plumes may have been present and for the presence of excessive cold starts. The percentage of 2006 and newer model vehicles with HC measurements in excess of 250 ppm hexane are shown by hour in Table III-3. Only hours are calculated in which at least 15 vehicles up to five years old were measured with VSP in the 5-20 kw/t range. Water droplet interference or excessive vehicle cold starts are likely when the percentage of vehicles up to five years old with HC greater than 250 ppm exceeds 5%. Table III-3 indicates the 5% threshold was exceeded once on the morning of September 19th when two vehicles had emissions greater than 250 ppm HC. The temperature was 54^F, which is above the typical temperature for steamers. This appears to be an isolated case where two higher emitters were measured in the same hour by chance. The data were retained and included in the reported emissions.

Table III-3 Percent of 2005 & Newer Models with HC Greater Than 250ppm

		Hour Beginning												
Day	Site	6	7	8	9	10	11	12	13	14	15	16	17	18
12-Sep-11	RI007	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%	1%	0%	0%
13-Sep-11	RI001	0%	0%	3%	1%	0%	0%	0%	0%	0%	0%	1%	0%	0%
14-Sep-11	RI003	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
15-Sep-11	RI005	0%	0%	0%	0%	0%	2%	0%	0%	0%	#N/A	#N/A	#N/A	#N/A
16-Sep-11	RI007	2%	0%	0%	0%	0%	0%	1%	1%	0%	0%	1%	0%	0%
17-Sep-11	RI011	#N/A	3%	0%	0%	0%	1%	1%	0%	1%	0%	0%	0%	0%
19-Sep-11	RI003	8%	0%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
20-Sep-11	RI002	#N/A	0%	0%	3%	3%	0%	0%	0%	0%	0%	2%	0%	0%
21-Sep-11	RI005	0%	0%	1%	0%	0%	0%	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A

d) Screening of Day-to-Day Variations in Emission Values

Each day's emission measurements of 2006 and newer model year vehicles were ordered by value and divided into ten groups or deciles each containing an equal number of the ordered measurements. Day-to-day decile emission values were compared for 2006 and newer vehicles. Only a small percentage of these newer vehicles are expected to have high emissions. We expect, therefore, their intermediate decile emission values should not vary significantly from day-to-day, from site-to-site or between RSD units. In Figure III-2, the daily HC decile values of measurements are plotted side-by-side. The right hand legend indicates the color of each decile number. This comparison revealed median values for 2006 and newer model year vehicles that ranged day-to-day from -8.4 ppm to -0.3 ppm. Although these variations are well within the HC specification of the RSD units they are significant compared to average fleet emissions for newer vehicles.

The most likely explanation is that this represents the limits of accuracy in the daily instrument set-up although it is unusual that the median would be negative on all days. For HC, an adjusted set of values was created by direct addition or subtraction of a daily offset that would set the daily median values to zero. We believe this is appropriate since the median I/M test result for new models is normally zero or very close to zero. The results of the correction are shown in Figure III-3 and analyses shown later in this report used the adjusted HC values.

Day-to-day decile CO, NO and UV smoke values for 2006 and newer model year vehicles are shown in Figures III-4 to III-6. Median values for CO, NOx and smoke were +0.004% to +0.034%, +2 to +5 ppm and -+0.005 to +0.016 respectively. These values appear reasonable and adjustments were not applied to these pollutants.

Figure III-2: Daily HC Deciles

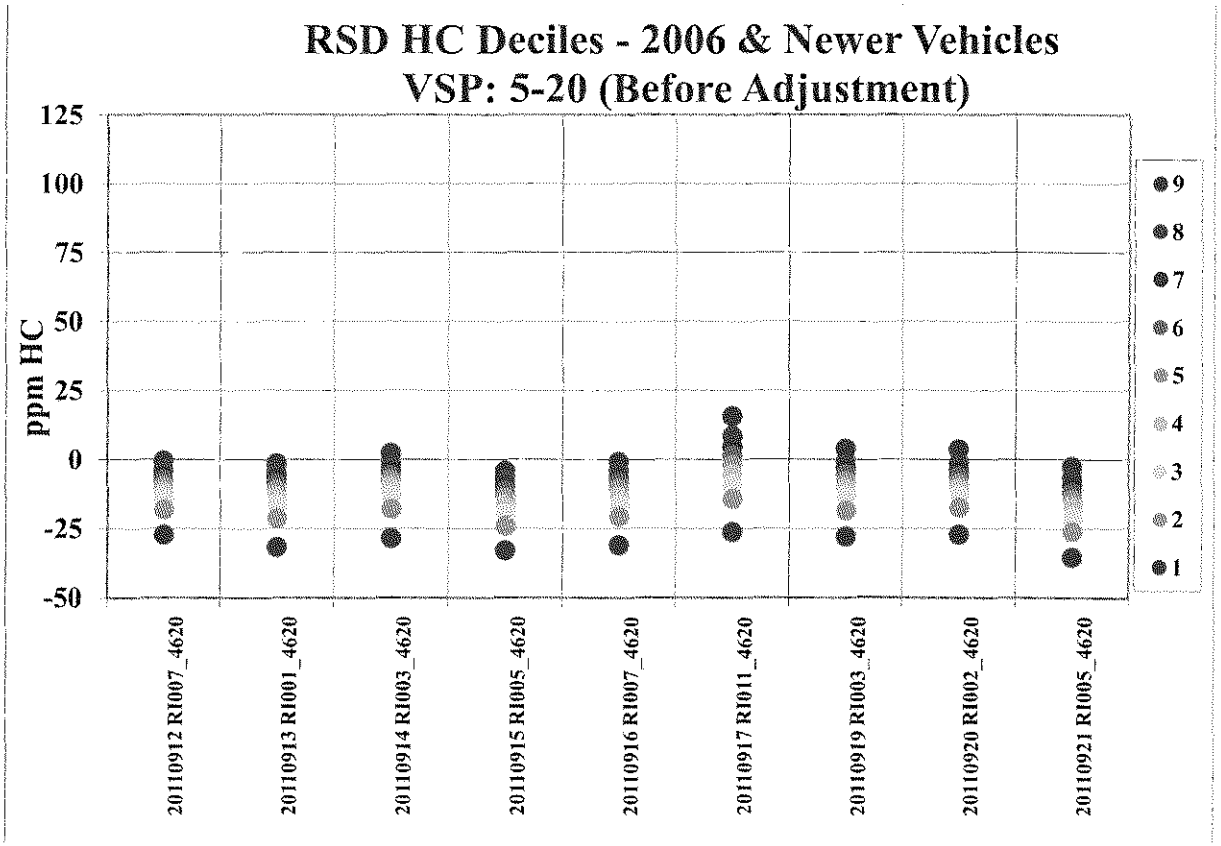


Figure III-3: Daily HC Deciles – After Adjustment

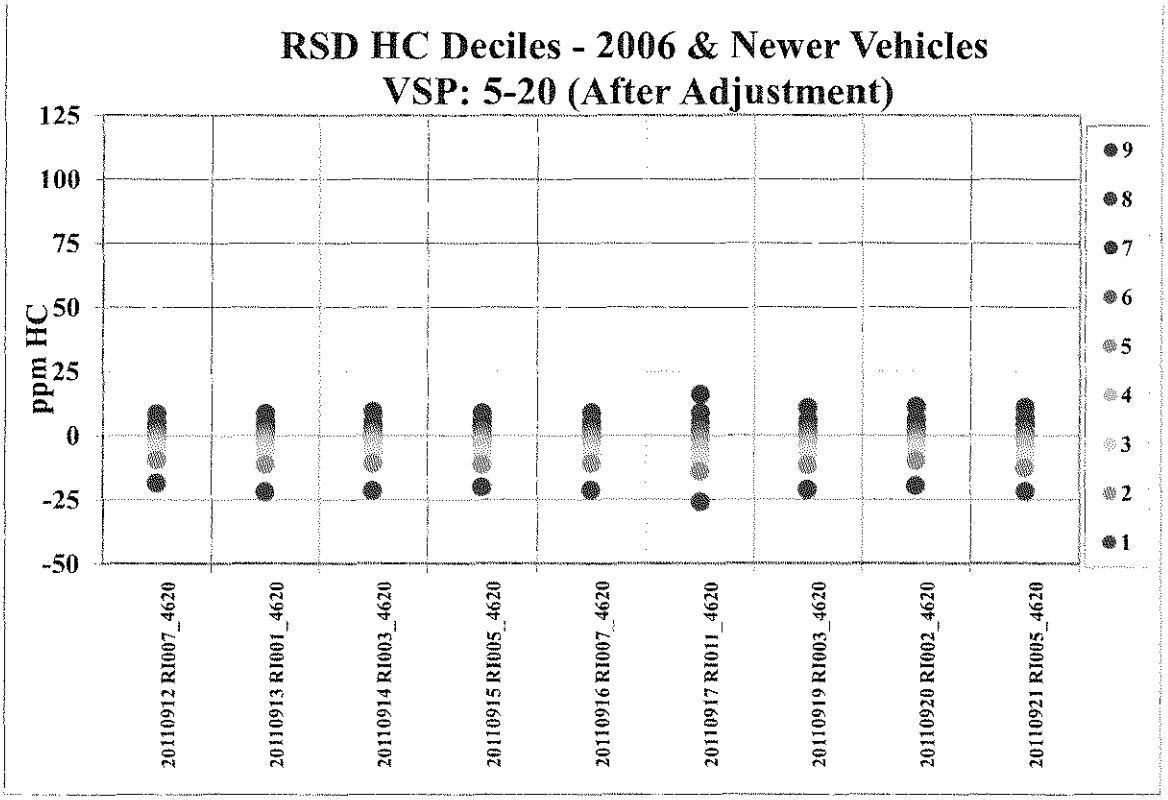


Figure III-4: Daily CO Deciles

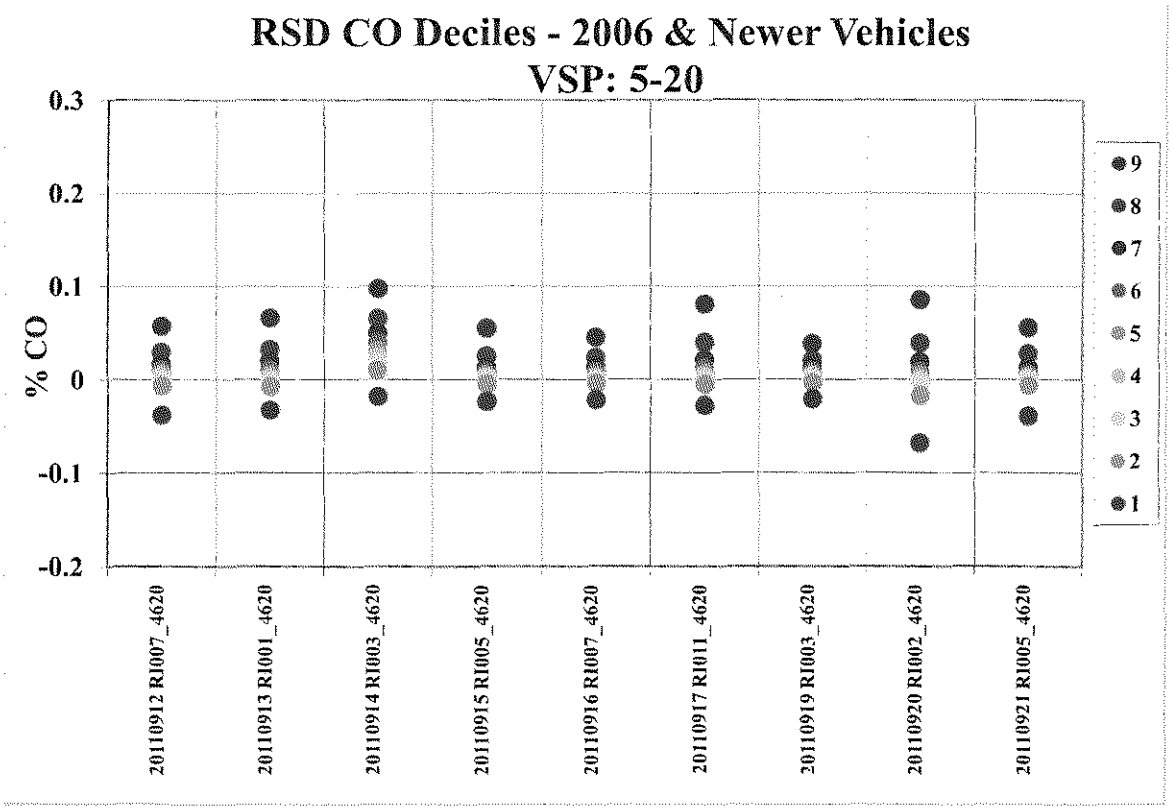


Figure III-5: Daily NO Deciles

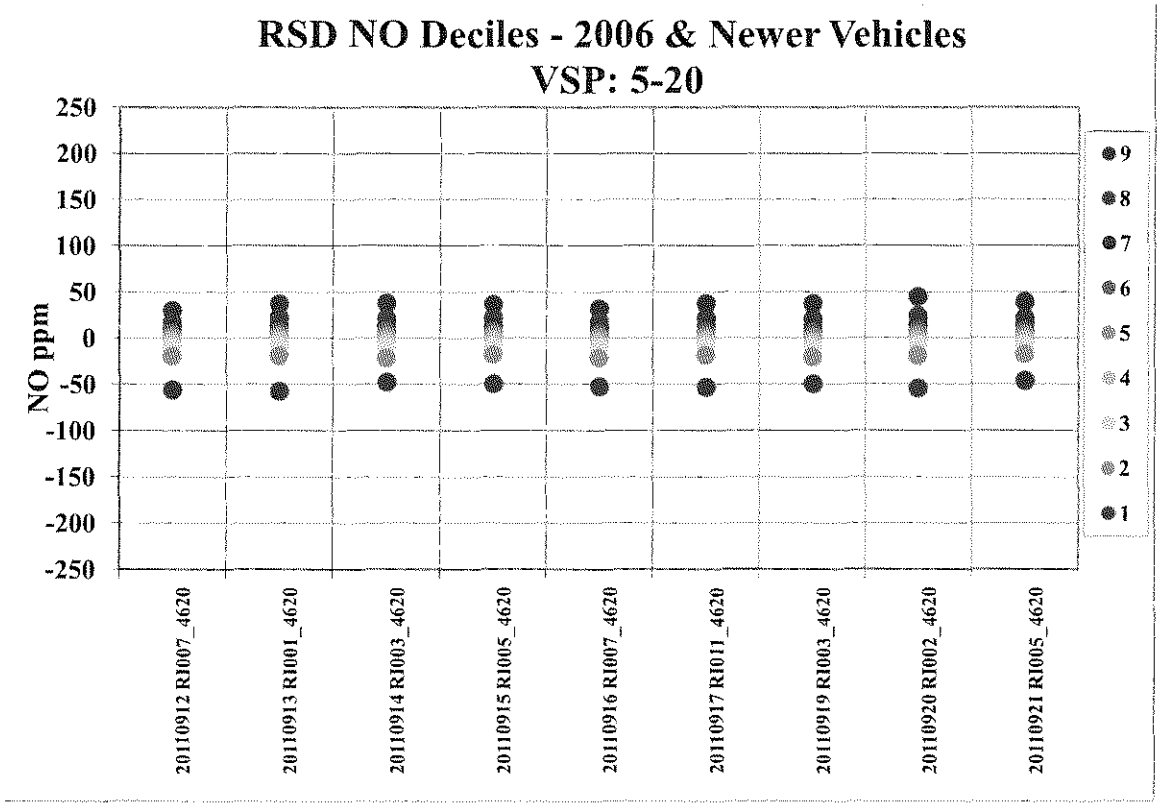
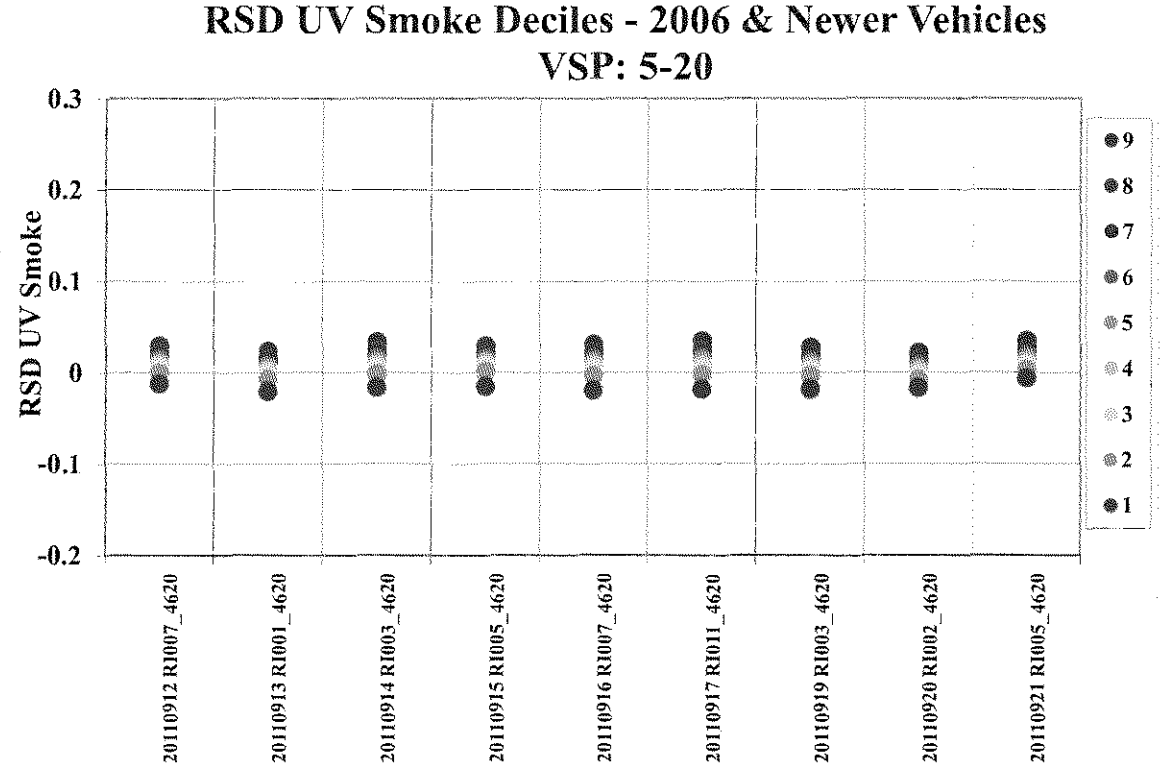


Figure III-6: Daily UV Smoke Deciles

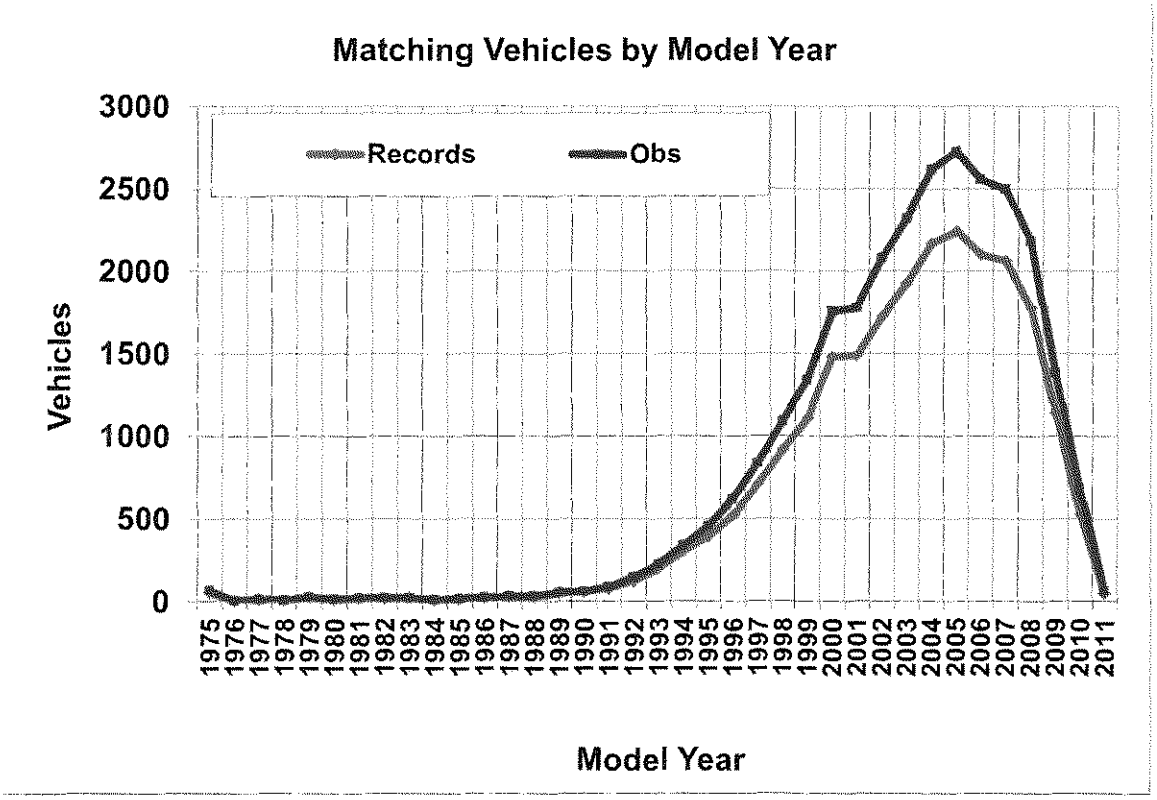


4. The Registration Matching Process

Vehicles measured by remote sensing are identified using the vehicle plate. SysTech matched the plates to records of vehicles inspected as part of the emissions and safety test program and to vehicle registrations to determine the vehicle identification number (VIN) and obtain the information about each vehicle, e.g. model year. Where there was duplicate information for a plate, the information associated with the newer model year was used. In 366 instances, more than one vehicle information record existed with the same newer model year and the same plate. In these cases the vehicle information was not used.

Out of the 32,109 screened RSD records with RI plates 25,747 (80%) were matched to specific vehicle information. The distribution of unique vehicles by model year is shown in Figure III-7. It appears that a lower than expected number of 2009-2011 model plates were matched. The sales cycle for 2009 and 2010 models were complete by the time of the survey in September 2011 but the numbers matched to registrations were only 63% and 31% of the 2008 models. 2008 models were also fewer than 2003 to 2007 models but this is believed a result of the recession.

Figure III-7 Matched Vehicles and RSD Measurements by Model Year



IV. On-Road Emissions

A. On-road Fleet Emissions Distribution

The following four charts show the emissions for each 1% of measurements rank ordered by increasing values for HC, CO, NO and smoke. These distributions include emissions from vehicles with out-of-state plates. The patterns are typical and show the majority of vehicles have low emissions while about 5-10% of vehicles have much higher emissions.

Figure IV-1 HC Emissions Distribution

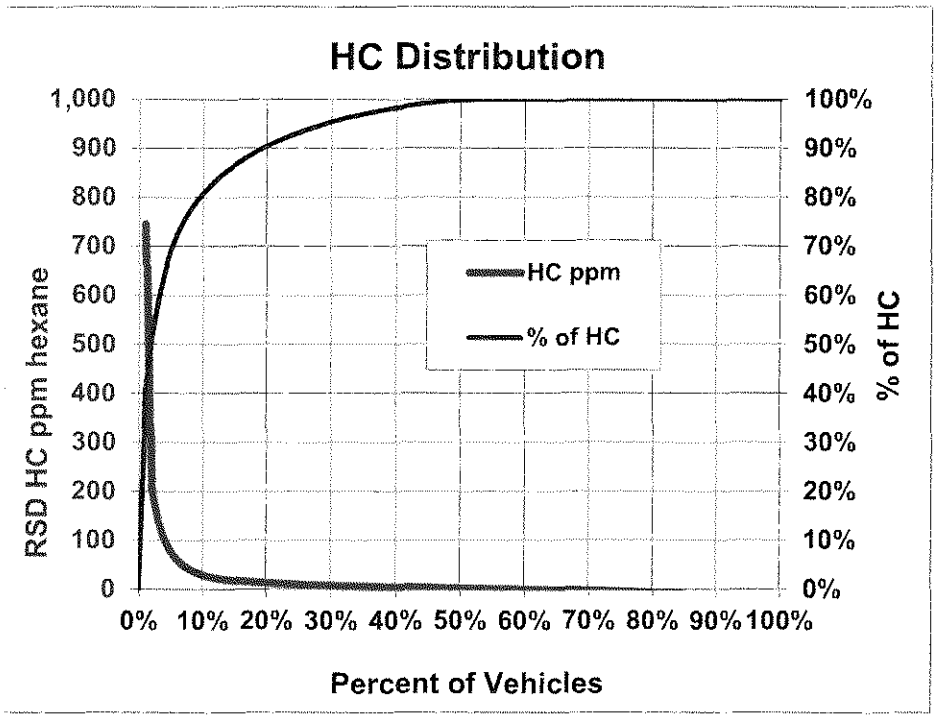


Figure IV-2 CO Emissions Distribution

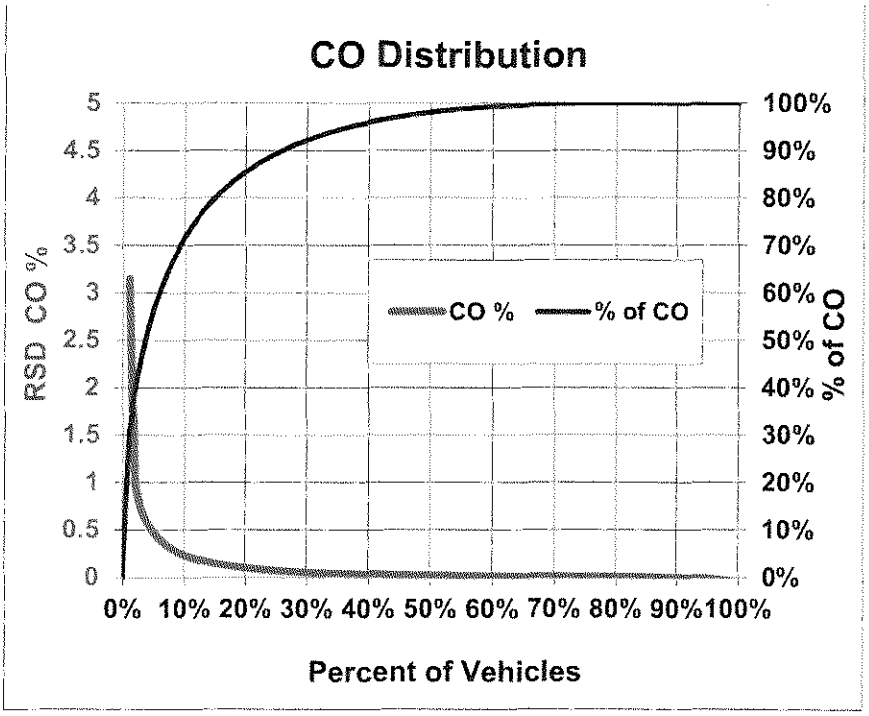


Figure IV-3 NO Emissions Distribution

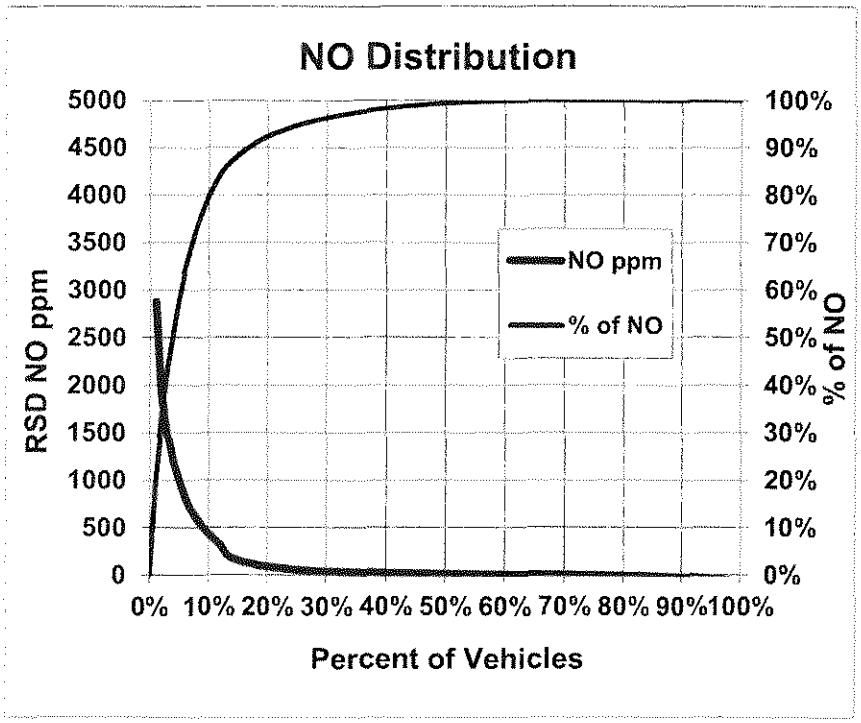
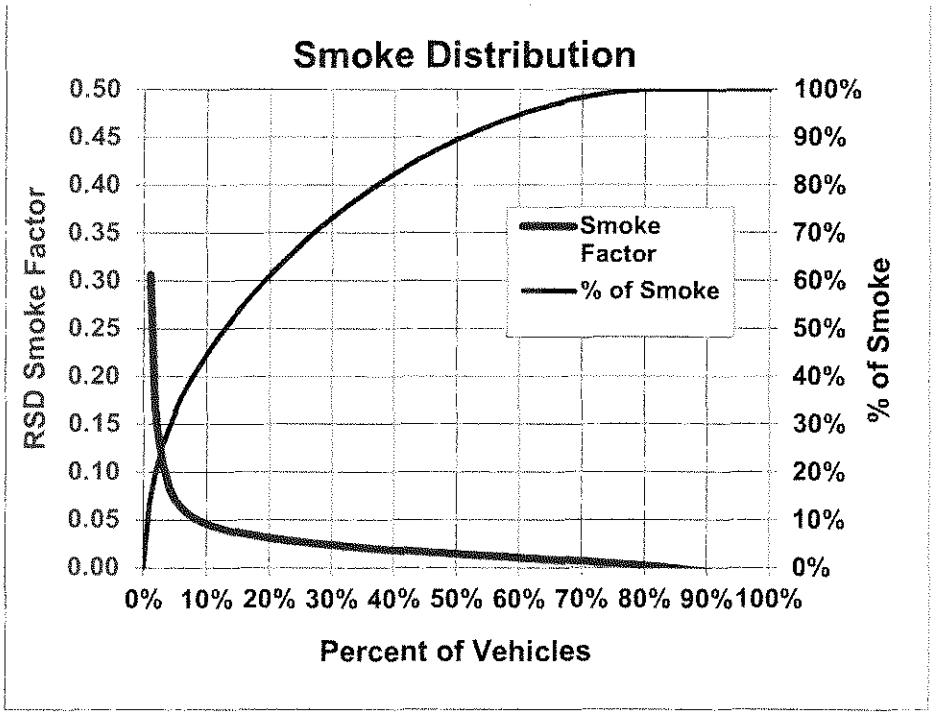


Figure IV-4 Smoke Emissions Distribution



B. *On-road Fleet Emissions*

Average on-road emissions of light-duty vehicles with Rhode Island plates were 0.10% CO, 15 ppm HC hexane and 138 ppm NO. Average smoke emissions were close to zero at 0.020 RSD smoke factor. (See Table IV-1).

Average emissions of vehicles from neighboring states were similar to the emissions of Rhode Island vehicles. However, no significance should be attached to this since the ages and models of neighboring State vehicles are unknown. Very likely these longer distance travelers reflect a newer mix of vehicles than the measured Rhode Island fleet.

Table IV-1 Fleet Average Emissions

State	N	CO %	HC ppm hexane	NO ppm	Smoke	VSP kW/t
RI	**32,109**	**0.10**	**15**	**138**	**0.020**	**12.47**
CT	461	0.09	9	95	0.019	12.75
MA	4,066	0.11	13	133	0.020	12.48
NH	183	0.09	4	83	0.017	12.72
Other	1,261	0.10	9	126	0.021	12.55
All	38,080	0.10	14	136	0.020	12.48

C. *Emissions by Model Year*

To view differences between vehicles in different age groups, vehicles were grouped into five-year model ranges. Model year ranges were used because of the small sample sizes for many individual model years.

Figures IV-5 to IV-8 show mean HC, CO, NO and Smoke measurements for each age group. The sample sizes for the 1985 & older, 1986-1990 and 1991-1995 age groups were 217, 179, and 1133 measurements respectively. The newer groups all contained more than 2,000 measurements.

As expected, newer vehicles have lower average emissions. The 1985 & older models were an exception and this group was investigated further. There was an increase in the number of reported 1985 and older models from 85 in the 2010 survey to 217 in the 2011 survey. These measurements had lower average emissions in 2011 than in 2010 and lower emissions than 1986-1990 models. The NO emission distributions were reviewed in Figure IV-9 to determine whether the NO distribution for 1985 and older models looked consistent for vehicles of that age. The distribution was similar to that of 1996-2000 models. It is suspected this was the result of incorrectly recorded model year or the most recent registration for the plate was not correctly matched. Therefore, the 217 measurements in the 1985 & older model year group were omitted from the estimate of contributions by age in Section IV.D.

Figure IV-5 RSD HC Emissions by Model Year

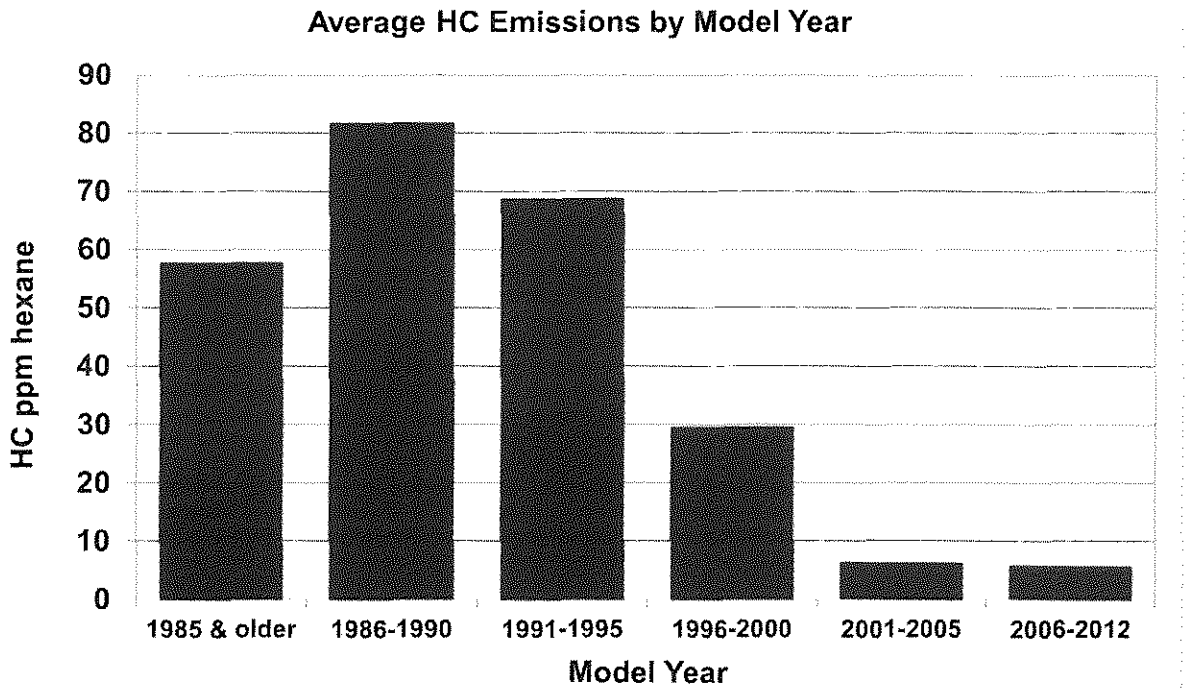


Figure IV-6 RSD CO Emissions by Model Year

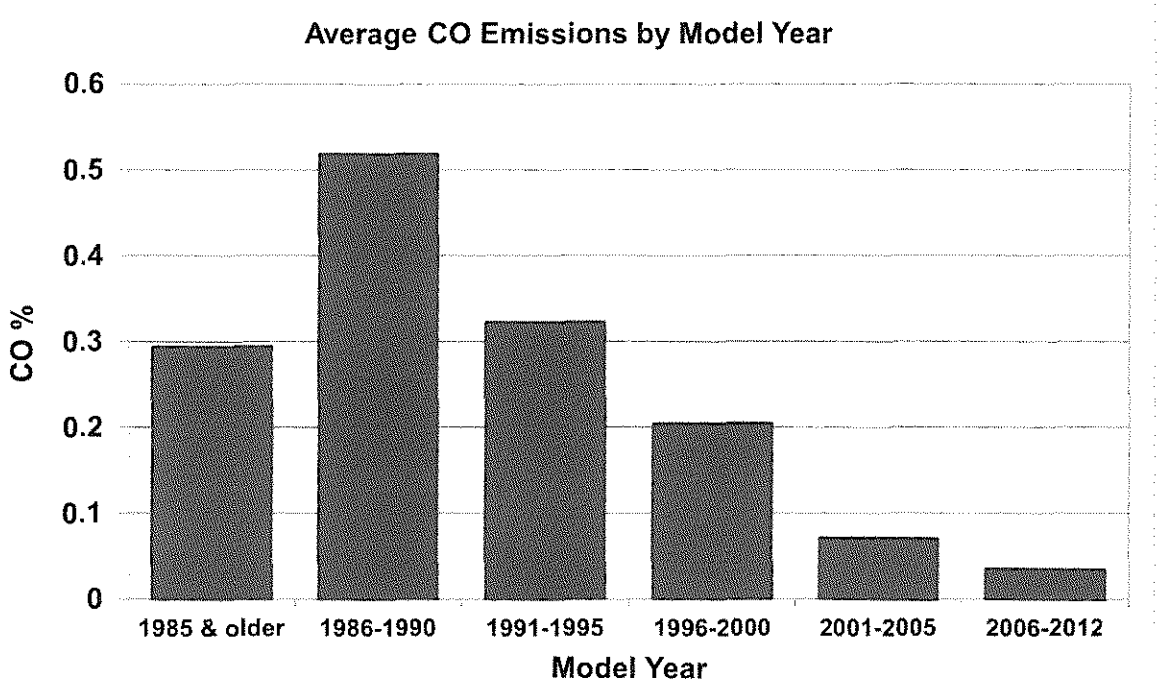


Figure IV-7 RSD NO Emissions by Model Year

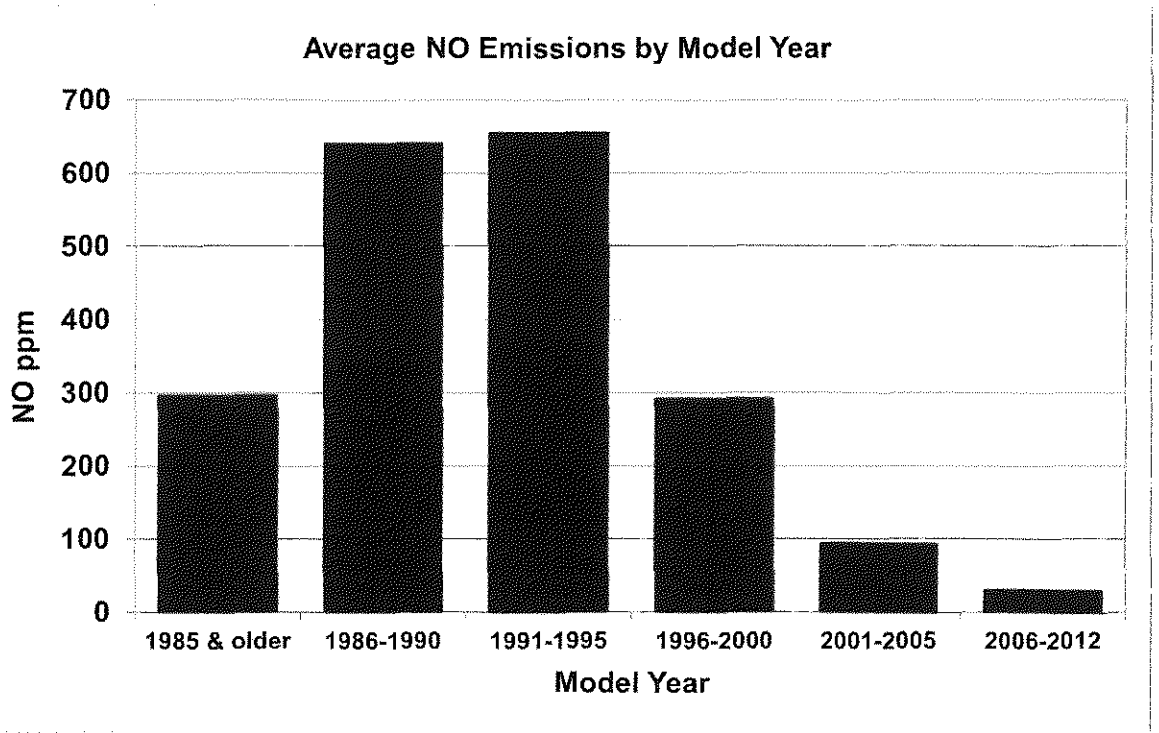


Figure IV-8 RSD Smoke Emissions by Model Year

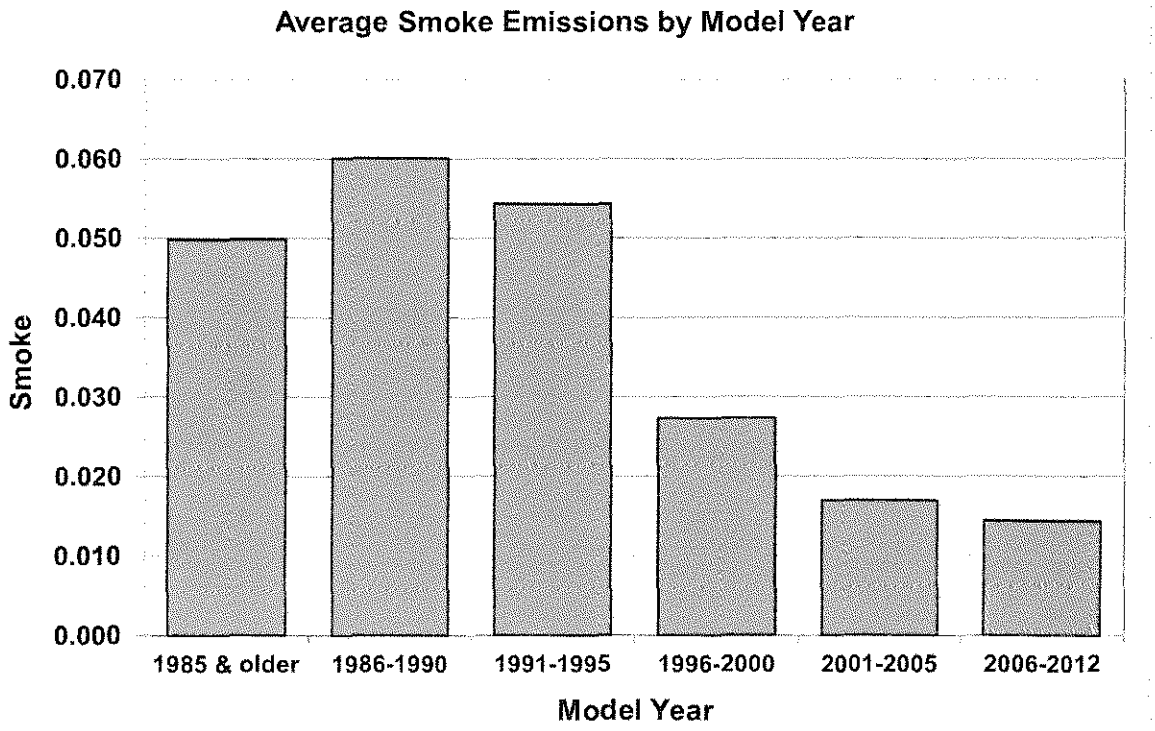
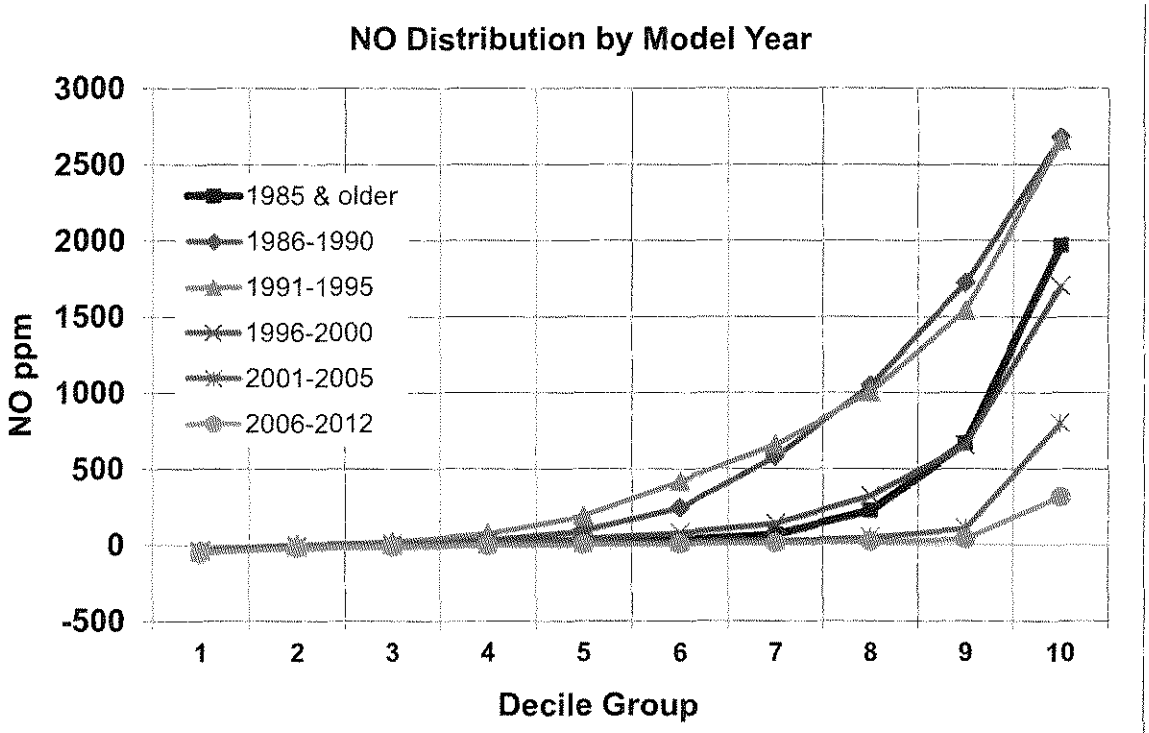


Figure IV-9 NO Emissions Distribution by Model Year



D. Approximate Contributions by Model Year

The following chart shows the approximate contributions of VMT and emissions from each age group. As noted earlier, a small number of measurements matched as 1985 and older models were omitted from this calculation as there was uncertainty as to whether the most recent registration for the plate was correctly matched. Other studies[8] have shown that the frequency with which vehicles of different ages are seen approximates their VMT.

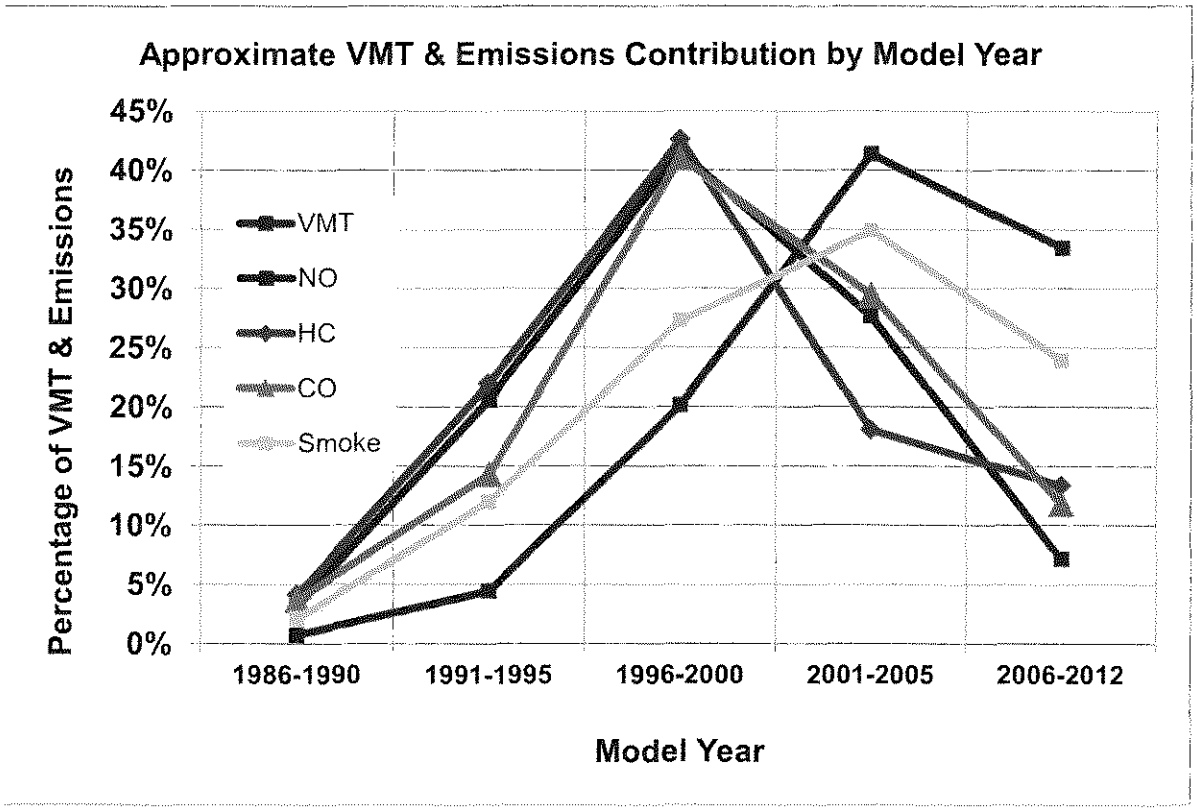
Vehicle models 1995 & older contributed only 5% of Vehicle Miles Traveled (VMT) but still accounted for 26% of on on-road HC, 18% of CO, 24% of NO.

Vehicle models 1996-2000 contributed 20% of VMT and 30-45% of emissions.

Vehicle models 2001-2012 contributed 75% of VMT and 30-45% of emissions.

On average, 1995 & older models were between six and twelve times dirtier than the 2001 and newer models.

Figure IV-9 VMT & Emissions Contribution by Age



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